Title: Connecting Force and Energy on Inclined Planes

Brief Overview:

Students will explore the relationship between force, distance, and energy through qualitatively and quantitatively recording and analyzing the behavior of a cart as it is first dragged up and then released down an inclined plane. The open format of the exploration will leave room for ingenuity and test students' understanding of the principles underlying force and energy.

NCTM 2000 Principles for School Mathematics:

- **Equity:** *Excellence in mathematics education requires equity - high expectations and strong support for all students.*

- **Curriculum:** *A curriculum is more than a collection of activities: it must be coherent, focused on important mathematics, and well articulated across the grades.*

- **Teaching:** *Effective mathematics teaching requires understanding what students know and need to learn and then challenging and supporting them to learn it well.*

- **Learning:** *Students must learn mathematics with understanding, actively building new knowledge from experience and prior knowledge.*

- **Assessment:** *Assessment should support the learning of important mathematics and furnish useful information to both teachers and students.*

- **Technology:** *Technology is essential in teaching and learning mathematics; it influences the mathematics that is taught and enhances students' learning.*

Links to NCTM 2000 Standards:

- **Content Standards**

  Measurement
  The students will take appropriate measurements within the lab using a variety of techniques and tools and record those measurements with appropriate units.

- **Process Standards**

  Problem Solving
  Students will employ the methods of mathematics to predict the behavior of a cart rolling down an inclined plane.

  Reasoning and Proof
  Students will make and investigate mathematical conjectures on the relationship between force and energy.

  Communication
  The language of mathematics will be used to describe the behavior of the cart.

Connections
Students will use mathematics in a context outside of mathematics.

Representation
Students will use mathematical representations to interpret their results.

Links to National Science Education Standards:

- **Unifying Concepts and Processes**
  Students will gather evidence to support their own theory on the relationship between force, distance, and energy.

- **Science as Inquiry**
  Students will continue to develop an ability to plan and conduct scientific investigations.

- **Physical Science**
  Students will connect the major concepts of motion, force, and conservation of energy by developing the work/energy relationship.

Links to Maryland High School Science Core Learning Goals:

- **Concepts of Physics**
  Expectation 1: Students will know and apply the laws of mechanics to explain the behavior of the physical world.

Grade/Level:

This unit is meant for use in the 9th to 12th grades.

Duration/Length:

This lesson should take two to four class periods.

Prerequisite Knowledge:

- Students should have learned and had laboratory experiences in determining speed, distance, mass, time, and force.
- Students should understand concepts of mass, acceleration, force, distance, potential energy, and kinetic energy.

Student Outcomes:

Students will be able to:

- qualitatively describe the effect of changing force and distance on energy.
- state a mathematical relationship between mass, force, and distance.

Materials/Resources/Printed Materials:

- Lab instructions
- Spring scale, cart, track or board, meter stick, protractor, table clamp, right angle clamp and rods or some other means of altering the angle of the ramp with respect to the table (i.e., stack of books or bricks)
- Access to materials in the classroom that might provide students with varied means of qualitatively determining the energy of the cart at the bottom the inclined plane. (Lab materials and equipment commonly found in a physics/physical science classroom, such as meter sticks, stopwatches, photogates etc.) Make available to students as many different things as you can.

Development/Procedures:

The unit should follow a discussion in which students are introduced to the concepts and equations for kinetic energy and gravitational potential energy, and a brief discussion of the law of conservation of energy. The lead-in could be to tell students that the energy equations and the law of conservation of energy could all be derived from Newton's laws. Ask them to try to make that connection. Relate the learning to their own real-world experience by asking what forces are at work during a roller coaster ride, and how those forces relate to the coaster's energy at points along the ride. Ask them how they believe changing the slope of the hills will affect the ride, and what factors will affect the speed of the ride and the forces acting on the riders. Without giving definite answers to these questions, explain that they will research the answers in the following lab.

In Part I of the lab, it is crucial that the students have a variety of possibilities available to them so that they can truly determine the cart's energy however they want. On the day prior to the lab, set out a wide variety of tools that could possibly be used to determine the energy of a cart at the bottom of an incline. Have students read through the prelab and first part of the procedure. For homework have them determine the means they will use to find the cart's energy.

For example, they could measure speed at the bottom of the incline after release using a meter stick and stopwatch, or a using a photogate. They could have the cart drive a nail into a piece of cheese and measure the depth? They could use a long straight area and measure how far the cart will go off the end of the ramp. They could measure how much weight it will move, or how far it can push something. The method should be left to the imagination of the group, and the more that is available to them the more imaginative they are apt to be.

In Part II of the lab it is critical that students understand that they are testing a hypothesis, and that they will not be penalized if their results show that the hypothesis was incorrect.

Many students will have difficulty with the open format of the lab since most of their lab experience is probably very structured. An assessment tool that encourages creativity and risk taking should be shared with the students prior to beginning the lab.

Assessment:

The following may be used to assess student learning:

1. Collect labs and determine if students successfully completed them.
2. Determine if student choice of method and materials to determine the energy given to the cart was effective.
3. Determine if students correctly identified the equation (change in) Energy = Force x distance OR CORRECTLY DETERMINED THAT THE EQUATION THEY CAME UP WITH RELATING FORCE, DISTANCE, AND ENERGY WAS INCORRECT, and then used their data to refute their hypothesis and amend their equation.

One possible scoring rubric is as follows:

	2 Points	1 Point	0 Points
Creativity	Student used new materials or old materials in a different way.	Student used materials in a manner consistent with past labs and demos.	Student failed to select appropriate materials.
Reasoning	Student chose materials that allow for measurement of the energy.	Student chose materials that inconsistently assessed energy.	Materials chosen could not assess the cart's energy.
Accuracy	Quantitative data and analysis were recorded and performed accurately.	Quantitative data or analysis was recorded and performed accurately.	Quantitative data and analysis were not performed or recorded accurately.

Extension/Follow Up:

In the ensuing discussion one may link the results of the lab to the energy given to a roller coaster being hauled up the first incline. Use free body diagrams and vector representation of forces to determine the force and distance up the first incline and then relate this to the gravitational potential energy of the coaster at the top of the incline and the resulting speed and kinetic energy of the coaster at the bottom.

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Lab: Connecting Force and Energy on Inclined Planes

Purpose: At the end of the lab the students should be able to:

- qualitatively describe the effect of changing force and distance on energy.
- state a mathematical relationship between mass, force, and distance.

Materials:

Spring scale	Table clamp,
Low friction cart	Tack or board
Meter stick	Protractor

Right angle clamp and rods or some other means of altering the angle of the ramp with respect to the table (i.e. stack of books or bricks)

Prelab:

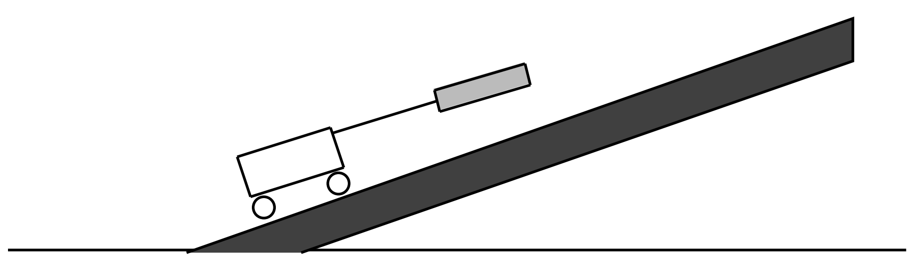
Prior to beginning the lab you must have a written statement outlining how you plan to determine the energy of a cart after it is released and has reached the bottom of an inclined plane. You may use any of the physics equipment set out in the classroom or equipment brought from home as long as safety and sanitary standards are met.

Procedure:

Part I: Qualitative Analysis

1. Set up the track so that it rests at roughly a 30-degree angle as shown in the diagram below.

2. Place the cart at the bottom of the track and slowly drag it to the top of the track using the spring scale. Next release it down the incline and be sure to catch the cart at the bottom.



3. Your task in the first part of the lab is come up with your own means of qualitatively determining what factors affect the energy given to the cart as it is dragged up the incline. For example, does the cart have more energy when dragged a short distance up a steep incline or a long distance up a gradual incline?

4. Set up your method for determining the energy of the cart at the bottom of the ramp.

5. Set the track to a 30-degree angle, raise the cart to the top of the track and release it, allowing it to travel at least to the bottom edge of the track. Evaluate the amount of energy the cart has at the bottom of the incline based upon your method of evaluation.

6. Adjust the angle of the track, drag the cart back to the same elevation (NOTE THIS MEANS THE SAME VERTICAL DISTANCE FROM THE TABLE TOP NOT THE SAME DISTANCE ALONG THE TRACK), and release it again. By your evaluation, did the amount of energy the cart had increase, decrease, or stay the same? How did the force used raising the cart and the distance the cart moved along the track change?

7. Repeat Step 6 for two more angles, and record the results (increase, decrease, same) below.

8. Now, drag the cart to three different heights with the track at the same angle and again evaluate the energy stored in the cart. Where was it greatest? Least?

9. Drag the cart to the end of the track and release it for the track at three different angles. Note that in this case the distance the cart is dragged is the same but the force and elevation of the cart are different. Again record the angles used. Where was the stored energy the greatest? The least?

10. Finally, compare your results with those obtained by another group that used a different means of measuring the energy of the cart. Did they agree? Whose method do you think was more accurate? Support your answer.

Part II: Quantitative Analysis:

1. Based on your observations in Part I, write a hypothesis on the mathematical relationship between distance, force, and energy.

2. Either using the method from Part I, or another method, design an experiment to test the equation listed above, take data, and analyze the data.

3. On separate paper, list the hypothesis you tested, the materials that you used, a brief procedure, and the outcome of your experiment. Be sure to explain at the end if your hypothesis was supported, and if not, what new conclusion the evidence steered you toward.